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Determination of Compressional and Shear Wave Velocity During Triaxial Compression: A Laboratory Manual

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The Naval Research Laboratory has modified a triaxial compression apparatus to include compressional and shear wave transducers for the purpose of measuring changes in compressional and shear wave velocity during consolidation. This report specifies the procedures and equipment used for this purpose.

In general, the procedures are those required for a standard triaxial compression test with the following exceptions: (1) the additional steps required to obtain velocity data are included and (2) detailed procedures for shearing the sample have been excluded since determining shear strength is not our primary objective, although the modified apparatus can still be used for this purpose.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

DETERMINATION OF COMPRESSIONAL AND SHEAR WAVE VELOCITY DURING TRIAXIAL COMPRESSION: A LABORATORY MANUAL

INTRODUCTION

The usual goal of triaxial compression testing is to obtain shear strength data on sediment or soils. At the Naval Research Laboratory, we are using triaxial test apparatus primarily to look at the changes in compressional and shear wave velocity that accompany changes in consolidation. This laboratory manual is intended to be a step-by-step procedures manual for using our triaxial compression apparatus and ancillary equipment for this purpose.

In general, the procedures are those required for a standard triaxial compression test with the following exceptions: (1) the additional steps required to obtain velocity data are included and (2) detailed procedures for shearing the sample, the main event in conventional triaxial compression, have been excluded since determining shear strength is not our primary objective.

Neither the equipment nor this manual should be regarded as foolproof. You should familiarize yourself with the individual operations manuals for each component of the system before proceeding.

SETTING UP THE TRIAXIAL CELL

Preparing Deaired Water

1. Initially, all switches and valves on all of the triaxial compression equipment and control panel should be in the off/closed position. Before attempting to operate the GeoTest Nold DeAerator make sure that the control box is plugged in and also that the deaerator and vacuum pump are plugged into receptacles.

2. To Fill the Deaerator: **Connect the intake hose** to the water tap. **Open the Vent Valve** (full counterclockwise position). Then **turn the control switch to "Fill DeAir"** and **turn on the tap water** (to a very low flow rate). If the deaerator is nearly empty, pause during filling for a few minutes (at the half full point) to allow the pressure in the deaerator to dissipate. Fill only to about three-fourths full. **Turn off the water tap,** then move the **Control Switch to the first "Off" position.**

3. **Close the Vent Valve** (full clockwise position). **Turn on the vacuum pump**, (first the switch on the pump itself, then the one on the control box). Then, **open the Vacuum Line** valve to the deaerator and **open the pinch clamp** on the vacuum hose. Next, turn the **control switch to "DeAir."** Water will start to swirl and gases bubbles will be observed to leave. When the deaerator starts bumping (cavitation and nucleation), allow it to do so for about 10 minutes. Then, **turn the Control Switch to the next "Off" position** (between Deair and Pump) and **turn the vacuum pump off** (switch on the pump, itself). **Close the Vacuum line valve and the vacuum hose clamp**. Next, **open the Vent Valve** (full counterclockwise position) and allow a few minutes for the system to reach normal pressure.

Deairing the Lines

1. If air is present anywhere in the lines (tygon tubes) you need to remove it. This will require flushing the tubes with deaired water. You may have to disconnect portions of the tubing for this.

2. To distribute water from the deaerator, make sure its vent valve is fully open, then turn its **Control Switch to "Pump."** Immediately **open Valve A** on the triaxial unit you are going to use (Unit A or B). This is the main valve to allow water into the distribution manifold.

3. It is especially important to remove all air in the drainage tubes from the sample cap and pedestal. With the deaerator distribution pump running, **open the valves marked Drain, A, D, F, P, and Q** (Figure 1). Put a bucket or beaker under the drain and then **slightly open valve M**. This will allow water to flow through one of the pedestals two drainage tubes onto the floor of the triaxial cell and out through the drain. Allow water to flow until all air bubbles are removed, then **close valve M**. Drain the other pedestal tube by **fully opening valve O and slightly opening valve N**. When no more air bubbles are present, **close valve N, then valve O,** in that order. Remove air from the cap's drainage tube by immersing the cap in a small beaker of water. **Open valve G**. When no more air bubbles emerge from the cap, **close valve G. Close the Drain and valve P**. Now **open valve B** and **slightly open valve P**. Water will flow out of the orifice in the triaxial cell floor in front of valve P. Be prepare to soak up the overflow with a sponge or paper towels. Allow the flow to continue until there are no more air bubbles, then **close valve P**.

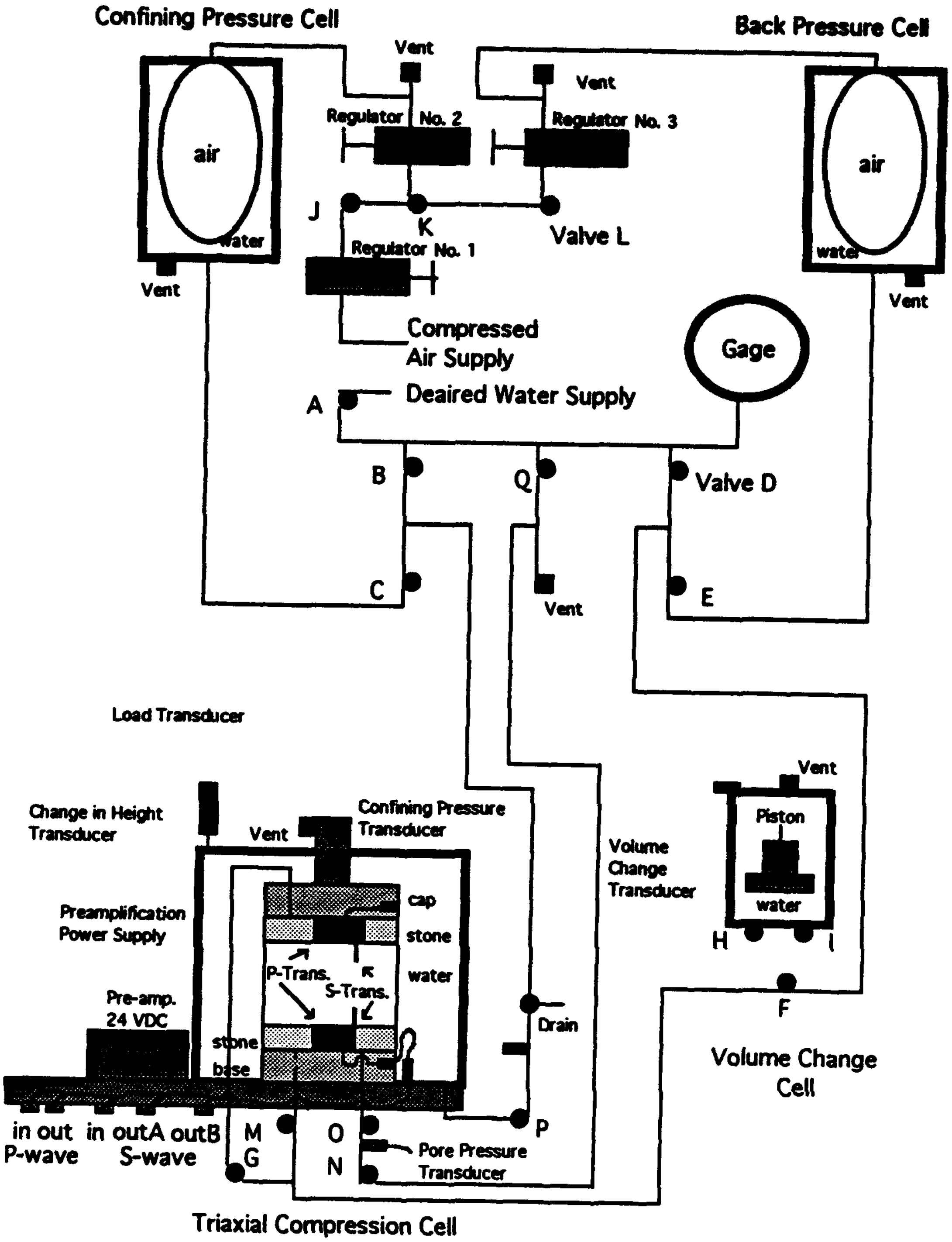

Figure 1. 5000 Kgf (WF10052) Compression Machine (modified)

4. Shut off the deaerator pump and **close all remaining valves.**

Preparation and Mounting of the Sample

1. The pedestal and cap have specially fitted porous stones. Boil these in water for about an hour to break up, and remove, encrusted sediment particles which can severely decrease the permeability of the stone. Allow the stones to cool, then position them on the pedestal base and Lucite cap and secure them with plastic screws. Cut pieces of filter paper to circles of the same size and place them over the stones in order to prevent them from becoming clogged with sediment as a result of contact with the wet sample. Do this before removing the sample from its core liner in order to avoid desiccation of the sample from prolonged exposure to room temperature air.

2. Retrieve your sample from the refrigerator and record the sample number on a copy of the Physical Properties data sheet (Appendix A). Remove the wax, tape, and end caps from the core liner containing the sample. Extrude the sample, using the wooden piston extruder or other suitable device, in the same direction as the core entered the liner (up direction) in order to avoid liner-sample contact disturbance. Immediately (to avoid desiccation) collect two small pieces of the core (about 5 to 20 grams each) in weighed and numbered sample tins for water content measurements. Record the weights requested for water contents on the Physical Properties data sheet. Place the two water content samples in the laboratory oven to dry for 24 hours at 100^0 C to 105^0 C. Remember to remove and weigh them the next day and to complete the water content calculation on the data sheet.

3. Slice off about a 1-cm-thick vertical section of sample from the top of the extruded core and from it, collect a pre-consolidation fabric sample by inserting one of the small plastic fabric cylinders through the slice, perpendicular to bedding, with as little sample disturbance as possible. Place filter paper over each end, add a very small bit of water soaked sponge, then cap and label (sample identification number on top and bottom and note that it is a "preconsolidation" sample) the cylinder. Seal the cylinder with electrical tape.

4. Cut a 7 cm (or less) length from the extruded core and mount it on the sample trimmer. Leave any remaining whole round core (in excess of 7 cm) in its core liner. Recap and relabel the core. Then reseal the liner with electrical tape. For the sake of uniformity, it might be advisable to decide on a standard sample length for all tests. As presently

configured for velocity transducers, our triaxial cells can accommodate a maximum sample length of 7 cm and require a sample diameter of 5 cm. Trim the mounted sample to a diameter of 5 cm by using the wire cheese cutter, spatula, or the osmotic trimming device.

5. Collect about 30 grams of trimmings for determination of index properties in the pycnometer, and about 70 grams for grain size analysis, in labeled plastic sample bags. Collect as much of the remaining trimmings as possible in a labeled plastic bag for Atterberg limits. Place these samples, along with the fabric sample and remaining whole round core, in the storage refrigerator.

6. It is advisable to have the trimmed sample on a metal or plastic tray of known weight while it is weighed and measured. Determine the samples weight, height, and diameter at the top, center, and bottom (in centimeters) to an accuracy of three decimal places and record the information on the Physical Properties data sheet. Complete filling out the other information requested on the Physical Properties data sheet.

7. Place one 5-cm o-ring around the lower end, and one around the upper end, of the split membrane stretcher to hold the two halves together. Cut a 5-cm-diameter rubber membrane down to a length about 4 cm longer than the sample length. Put the rubber membrane inside the stretcher with its edges folded over the outside at both ends. Record the weight of the stretcher and membrane on the data sheet. Make sure that no wrinkles are present in the membrane. Wet the membrane surface. Now apply suction until the membrane smoothly coats the inside of the stretcher. Lower the stretcher all the way down over the sample, then release the suction, letting the membrane envelop the sample smoothly. Weigh the stretcher, membrane, and sample and record the results. (From the sample dimensions and weight you can calculate a wet sediment density as a back up and check on the pycnometer results.)

8. Place the sample-membrane-stretcher-ring assembly over the cell pedestal and press down gently until the base of the sample is flat against the pedestal surface. It will then be flat against the compressional wave transducer with the shear wave transducer inserted into the sample. Unfold the lower edge of the membrane from the stretcher until it fits smoothly down over the pedestal (with porous stone and filter paper already in place). Now slide the o-ring from the lower end of the stretcher off the sample and down over the pedestal until it is in the o-ring notch on the pedestal. The o-ring should completely seal the membrane against the pedestal.

9. Place the lucite cap (with its porous stone and filter paper) on top of the stretcher, with the shear wave transducer aligned parallel to the one in the base, and push it down until it is firmly in contact with the sample. (It is very important to have the shear wave transducers in the cap and base aligned. If they are not, the shear wave signal transmitted through the sample will either not be received at all or will be polarized.) Unfold the membrane from the top edge of the stretcher up and around the Lucite cap. Push the remaining o-ring up over the membrane and cap into its grove. Make sure it completely seals the membrane against the cap. Avoid trapping any air bubbles inside the membrane. Remove the stretcher.

10. Make sure the drainage tube from the cap is attached; one end to the Lucite cap, the other to the floor of the cell in front of valve G. Plug the electrical connection from the cap transducers into the socket marked R on the floor of the cell. The flat portion of the plug must be aligned with the flat portion of the socket. Likewise, plug in the transducers in the base to the socket marked T.

Filling and Deairing the Lucite Cells

1. Place the lucite compression cell with its metal top, load piston, and transducer, over the sample without letting the piston press down on the sample (it is heavy enough to cause some consolidation of soft samples). A ring stand clamp can be used to keep the piston locked above the sample. The three holes along the outside edge of the metal top fit down over the three metal rods sticking up from the machine's base. Make sure the top and bottom of the lucite cell are seated in the o-ring grooves in the base of the triaxial machine and in the metal cap, respectively. Tighten the holding screws with your fingers until snug. Do not use a wrench! The o-rings fail to provide a seal if they get flattened out from over-tightening. Release the ring clamp on the load transducer piston and lower it until it just makes contact with the top of the sample. Secure the piston in this new position with the ring clamp in order to hold the sample in a vertical position without putting weight on it. Lower the transverse bar of the load frame until it just makes contact with the top of the piston. Do not allow it to put pressure on the piston. Secure the bar in this position with the lock nuts.

2. **Open the air vent screws** on top of all four lucite cells (i.e., the load cell, volume change cell, confining pressure cell, and the back pressure cell). To accomplish this, you will have to turn the confining pressure and back pressure cells upside down because their air vents are located on the underside of the bases. Be very careful; these cells (the two

large ones) are very heavy and the tubing breaks easily. **Open valves A, B, C, D, E, and Q.** Make sure value F is closed. Open the volume change cell: **move knob valves H and I to the full-inward position.** All remaining valves should be in the closed position. Also make sure that valve A on the other Triaxial Compression Unit is closed. There is not enough water pressure to fill both units at the same time.

3. If necessary, deair more water prior to filling the cells. The deaerator water distribution pump puts out about 5 lb of water pressure; not enough to fill all four lucite cells at the same time. Consequently, you will have to let them fill individually by doing some valve switching during filling. Start the flow of water from the deaerator to the triaxial cells by turning the **Control Switch to "Pump On."** Let the confining pressure cell (Figure 1) fill all the way until the air bladder is completely collapsed. This is important in determining the maximum possible load pressure available for consolidation. The bladder can only expand to the diameter of the cell. If you begin with a partially expanded bladder, the pressure exerted on the surrounding water at full expansion will be less than if you start with a collapsed bladder. **Close the cell's air vent.**

4. If necessary, prepare more deaired water. Let the back pressure cell fill to the top but do not collapse the bladder. This is also very important since water expelled from the sample during consolidation will need to flow into this cell. Space will be made available for this by forcing the volume of the back pressure cell's bladder to decrease, i.e., it must be partially expanded to begin with. However, it must not be full expanded as you will need to cause this cell's bladder to expand slightly in order to provide back pressure (pore pressure). After filling, **shut the cell's air vent** and carefully invert both the back pressure and confining cells so that the air line-bladder connection is at the top (as shown in Figure 1).

5. Allow the volume change cell to completely fill with water, then **close its air vent.** Immediately **close all valves except A, H, I, and the air vent on the triaxial compression cell.**

6. To allow the triaxial compression cell (containing the samples) to fill slowly, **open valve B, and slightly open valve P.** When water begins squirting from the air vent at the top, **close the air vent and valves P, B, and A.** All valves should now be closed except for H and I. Immediately **turn off the pump** at the Deaerator.

7. At this point, there should be no air bubbles in the water lines or in any of the

cells. If there are air bubbles in a cell, reopen its air vent. Pump water from the deaerator through the cell until all the air is forced out the air vent. If any new air bubbles have appeared in the water lines to the cells, repeat the procedure for deairing the lines.

8. Mount the Linear Velocity Displacement Transducer (LVDT, for measuring the change in height of sample as it consolidates) between the load frame transverse bar and the metal top of the compression cell. Set the transducer at about mid range.

DATA ACQUISITION

1. Refer to Table 1 for a list of data acquisition tasks that must be accomplished during each test. Step-by-step procedures for each task are presented in the following sections in the order in which they are to be performed. Procedures for calculations and interpretation of test results are beyond the purview of this manual. If necessary, you should consult one of the many text books on the principles of geotechnical engineering and soil mechanics for a discussion of mathematical and graphical interpretation of test results.

Compressional Wave Velocity

1. The correct connections between the Power Supply, Waveform Generator, Oscilloscope, and Power Amplifier are illustrated in Figure 2. Leave the Power Amplifier turned off and turn the others on. Allow a few minutes warm up time.

2. Set the frequency to 150 kHz by first pushing the Frequency Function key on the Signal Generator and then using the number keys. Likewise, set the amplitude to 1 Volt. The other settings should be pre-set. You can check them by pressing the respective function keys and referring to the settings specified in Table 2. Reset any functions that have been changed. <u>Make sure the Power Amplifier is turned off</u> (it puts out more than enough voltage to cause severe shock so always make sure it is off when you connect or disconnect cables during the test). **Connect the cable marked "In"** (Figure 2) to the connector on the cable box at the base of the triaxial cell, marked "In P" (Figure 1). **Connect the cable marked "out A"** to the box connector marked "out P". Do not connect the cable marked "out B". **Push the on buttons for channels 1 (receive) and 4 (transmit)** on the oscilloscope if they are not already on. There are two cable connections for each channel. Connections in use should be set to AC. Those not in use should be set on Ground. Now, **turn on the Power Amplifier**.

3. The oscilloscope screen gives you a plot of voltage (y-axis) versus time (x-axis).

TABLE 1 - DATA ACQUISITION TASK

Measurement	Task	Objective
1. Compressional wave delay time	Record oscilloscope send and receive signals	Compressional wave velocity
2. Shear wave delay time	Record oscilloscope send and receive signals	Shear wave velocity
3. Sample saturation	Determine B Factor	Back pressure required
6. Confining and Back Pressures	Record pressure A and B transducer output	Effective Stress
5. Change in sample volume	Record Δ VCD	Time compression curve/% consolidation
4. Change in sample height	Record Δ LVDT/Δ Platen	Velocity calculations

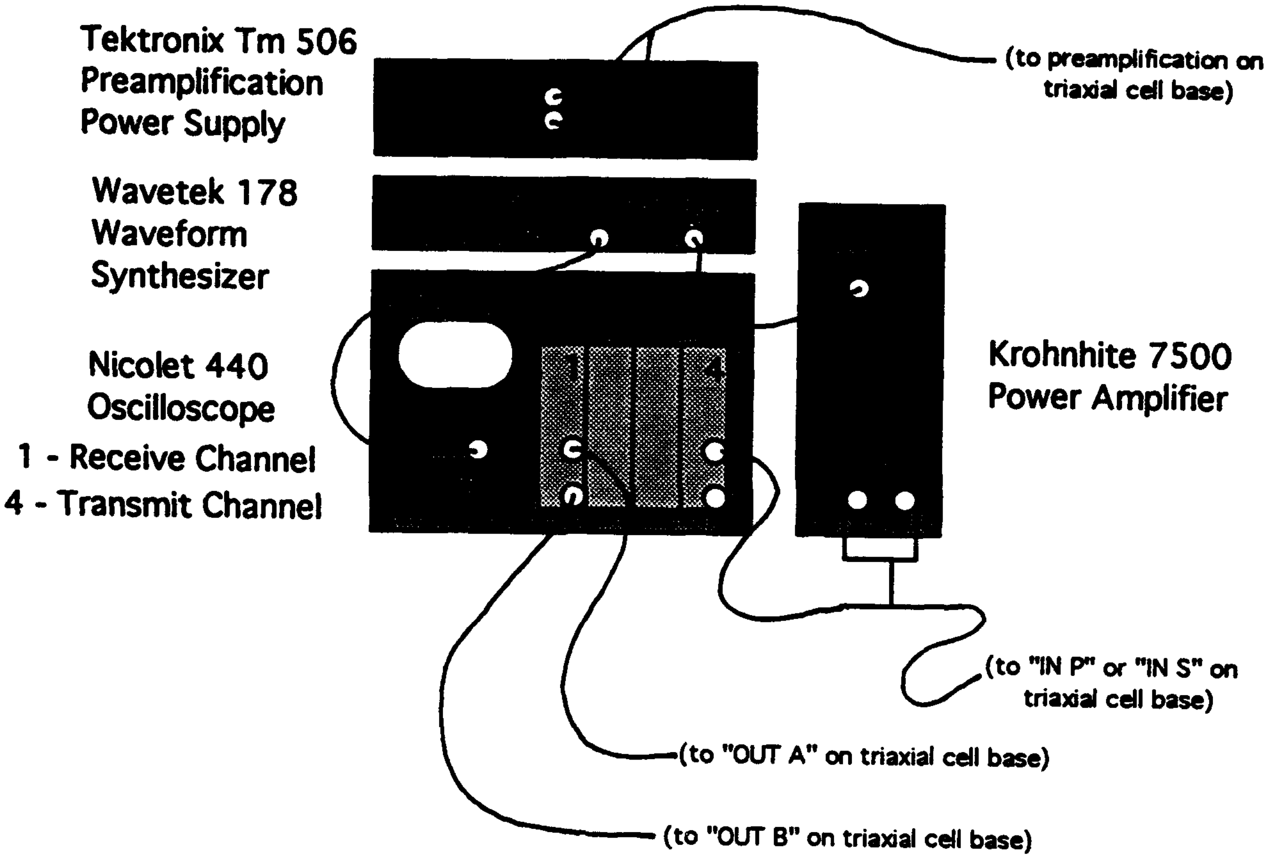

Figure 2. Configuration of Electrical Components and Connections

TABLE 2 - INITIAL SETTINGS FOR ELECTRICAL COMPONENTS

Component	Make/Model	Initial Settings
Pre. Amp. Power	Tektronix Tm 506	Power - on Red Switch - on
Waveform Synthesizer	Wavetek 178	Power - on P-wave: Freq. - 150 kHz Ampl. - 1 Volt S-wave: Freq. - 1.5 kHz Ampl. - 10 Volts P & S-waves: Ext/Int Trigger - 1 Burst - 1 to 3 Time - 0.01 Offset - 0 Volts Func. Sine - 0 Phase Ref. - Set Phase - 0 Deg. Start Freq.- 500 Hz SW Stop - 5 kHz Marker - 1 kHz Mark. Freq.- 1 [illegible]Hz Mode (upper) - 3 Mode (lower) - 0
Oscilloscope	Nicolet 440	Chan. 1(Rec.) - on + - AC, __ - AC Volts - as needed Chan. 4(Xmit)-on Volts - as needed + - AC, __ - Grnd. TIME - as needed Triggers - 1,1,1 Other Func. - do not change !
Power Amplifier	Krohnhite 7500	Power - on (Gain on 0-100, variable selection)

The upper portion of the screen should contain a sharp image of a single cycle (one burst) sine wave (the transmitted signal). The lower portion of the screen should contain the receive signal. If either of these signals is not clear and sharp, adjust the voltage axis setting keys on channels 1 and 4 and/or the time axis knob (marked TIME). You can also move the position of both signals up or down on the screen by adjusting the "Position" knobs on channels 1 and 4. If you still cannot get a clear, sharp signal, try changing the voltage function on the Signal generator or increasing the output from the power amplifier until you do. You can also change the frequency function but this is a last resort as it is desirable to have all of your compressional wave measurements at one constant frequency. Likewise, all of your shear wave measurements should be at a constant frequency.

4. **Position the white vertical cursor** (axis) line directly in the center of the trough of the transmitted signal by pressing the cursor keys. **Press the "ΔT/ΔV" button twice** to zero the time delay measurement. **Move the vertical cursor line** from the trough of the transmitted signal to the right until it is in the center of the first trough you can distinguish on the received signal. **Read the time delay** (i.e., the signal's travel time through the sample) indicated on the screen and **record this value on the Wave-Forms data sheet** under Zero Settings. Divide the sample height by the time delay to get compressional-wave velocity and record the results on the data sheet along with the other information requested.

5. At this point, the signals displayed on the oscilloscope should be recorded so that they can be reproduced later (either directly on the oscilloscope or by loading the signal data into a graphics program and plotting it). **Insert a 3.5 in. DS/HD diskette** in the floppy disk drive on the oscilloscope and **press the Menu button.** Use the white cursor keys to **select Disk** from the menu. If you have not previously formatted the disc, **select Format** and use the cursor keys to indicate a 1.44 MB format, then **push the Execute button.** After formatting is complete, **select Acquisition and Autocycle to Disk** from the menu, **then Execute.** The screen will now tell you that the transmitted and received signals will be stored in two separate files on the diskette and indicate the name and file number of each. If the oscilloscope has been turned off since the last time you recorded a signal it will default to WAVE0001WFT and WAVE0002WFT as the names and file numbers. You can use the cursor keys to reset the file numbers if you wish. It is desirable to give each recorded signal a unique number, i.e., 0001 and 0002 for the transmitted and received signals recorded after the first consolidation load, 0003 and 0004 for the signals

recorded after the second consolidation load, and so on throughout the test. It is also desirable to continue this procedure from test to test so that subsequent tests results will not have duplicate file numbers. **Record the file numbers** on the wave form data sheet (Appendix A). The oscilloscope will automatically switch to "Hold Last" mode to record the signals. It is finished recording when the light on the disk drive goes out. **After the drive light goes out, press the Live button** to return the screen to normal operating mode.

Shear Wave Velocity

1. Reset the frequency function on the Signal Generator to 1.5 kHz and the amplitude function to 10 volts (you may try other combinations of frequency and voltage if you do not obtain a good receive signal with these settings). Make sure the Power Amplifier is turned off and then **reconnect the "In" cable to the connector marked "In S" and the "out A" cable to the connector also marked "out A." Then, connect the cable and connector marked "out B."** You are now set up to measure the delay time for the shear wave signal. **Turn on the Power Amplifier** and follow the same procedure you used for measuring compressional wave delay time. **Calculate the sample height** minus the predetermined length of the shear-wave transducers (specified on the data sheet) in the cap and base and divide this value by the shear-wave delay time to get shear wave velocity. **Record these data** on the Wave-Forms data sheet under Zero Settings.

2. <u>Turn off the Power Amplifier</u>. **Disconnect all three cables from the base of the triaxial cell** and proceed with the triaxial test. You will need to repeat the entire above procedure, for both compressional and shear velocity, after each increment of loading during the Triaxial Compression Test (see Wave-Forms data sheet). Alternatively, you may wish to observe, and record, changes in velocity during compression. After completion of the test, turn off the Power Supply, Oscilloscope, Power Amplifier, and Signal Generator.

Saturation of the Sample

1. A two-phase system (a sample consisting of a liquid and a solid) is required for valid consolidation and permeability results. To eliminate any gas phase present, the sample must be put under pressure until the sample is saturated, i.e., all vapor has been completely dissolved and the sample's pore space is completely filled with fluid, i.e., the sample is saturated. This is achieved by "back-pressuring" the sample.

2. First, obtain zero pressure readouts for initial height (Platen height and LVDT reading), volume (VCD), confining pressure (Pressure A) and pore pressure (Pressure B) and record them on the Loading Sequence data sheet. To do this, first **make sure the transducer cables are plugged** into their correct sockets on the data acquisition cabinet (Figure 3). Turn the cabinet **power switch on.** A red light for each transducer should come on. **Turn the monitor and hard drive** and allow the system to boot up. The monitor screen cursor should read C:\DATA>. If it does not, **press Shift and F9** at the same time to get the command prompt C:\QBASIC. Then **type CD\DATA** to get C:\DATA> on the screen. Now run the data acquisition program: **type TriaxA (or TriaxB** if you are working on Triaxial Unit B), then hit the carriage return. The next prompt will ask you which LVDT you wish to use. **Type 1333 (or 1273** if you are on Unit B), then return. The next prompt will ask you to specify the duration of the test in seconds. **Type 5** and return. Wait while the data are printed on the screen. At the end of the test you will be asked if you wish to run another. Make sure the LVDT and VCD readouts are in range, i.e., they fall within the limits of the calibration curves diagrammed in this manual (Appendix B). If they are, **type** N (for no). The cursor prompt should read C:\DATA again. (You do not need to worry about saving the test data yet).

3. Make sure that air Regulator #1 is backed off (turn the handle counter-clockwise until it is loose) and that valves J, K, and L are closed. Also make sure that air Regulators #2 and #3, as well as the vents above them, are closed. Slowly **open the main compressed air supply valve.** Its gauge should read about 250 to 300 psi. Now slowly **open air Regulator #1** (screw the handle in, clockwise) until it reads about 10 psi.

4. **Open valves J, K, and L.** To expand the bladder in the confining pressure cell, and thereby apply an external pressure on the sample in the triaxial cell that can be read on the wall gage, **open valves B, C, and P.** Then **open air Regulator #2** until the wall gage reads a pressure of 3 psi. **Close valves B and C, then open valves D, E, G, M, N, O and Q.** The reading on the wall gauge should drop back to zero. To apply an internal pore pressure on the sample by expanding the bladder in the back pressure cell, **open Regulator #3** to 3 psi (read on the wall gage). **Close Valves D, E and Q.** Obtain pore pressure (Pressure B) and confining pressure (Pressure A) readings via the pore pressure transducer readouts (see paragraph 2, this section). Repeat the procedures outlined

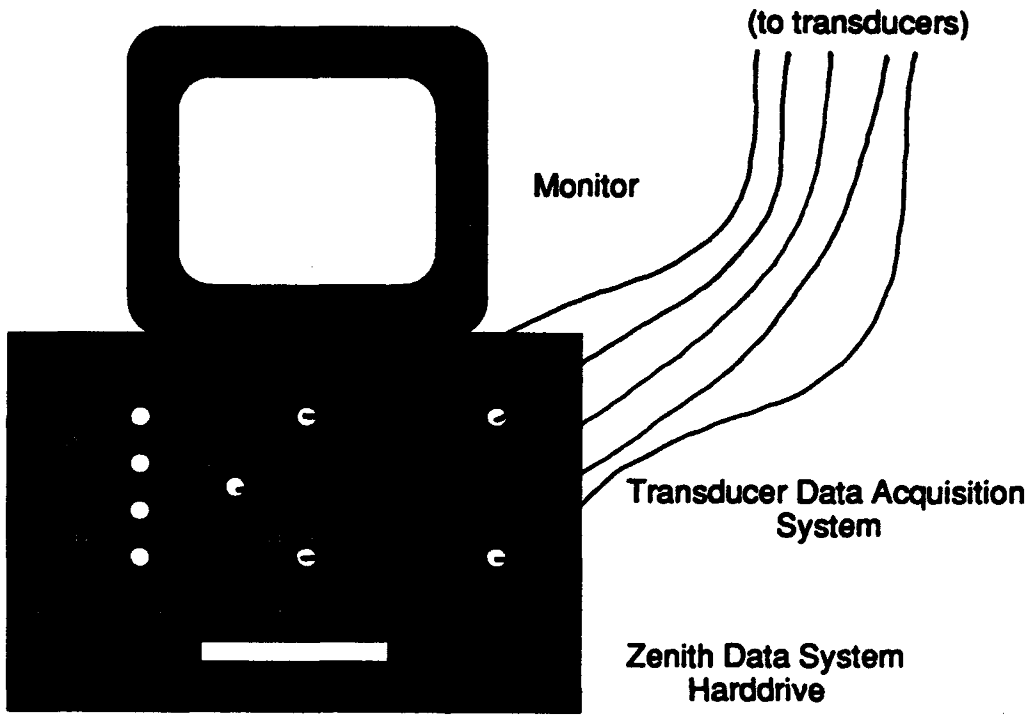

Figure 3. Transducer-Data Acquisition System Connections

in this paragraph with adjustments to air Regulators #2 and #3 so that both Pressure A and Pressure B transducer readouts are approximately equal. The bladders in both the confining pressure and back pressure cells will now be inflated so as to apply a confining pressure on the sample and an equal amount of pore pressure within the sample. Because these pressures were not applied simultaneously, some sample height and volume change may have occurred. These differences will be accounted for in the difference between zero readings and readings after the first load has been applied.

5. It is desirable to achieve saturation at the lowest possible pressure. This will be more likely to occur if you now let the sample sit over night to allow any gas present plenty of time to go into solution. Saturation can be obtained more quickly by simply incrementing the back pressure to a high enough value. However, since effective stress (load) is equal to the confining pressure minus the back pressure, higher back pressures mean that greater confining pressures are required to apply a given amount of load. Since there is an equipment design limitation on the confining pressure that can be applied, higher back pressures ultimately mean that the maximum load you can test at will be less. To determine the percent sample saturation, **Close valve I** (by placing the knob at the half way position) if it is not already closed. This closes the volume change device, thereby preventing the sample from drainage. **Open valves B and C. Obtain and note transducer readouts of Pressure A and Pressure B** by repeating the procedure in paragraph 2 of this Section. Raise the confining cell pressure by increasing pressure from Regulator #2 by 3 psi. Do not increase back pressure from Regulator #3. There is now a difference between cell (confining) pressure and pore (back) pressure which produces a load on the sample. As no pore water can be drained from the sample, its pore pressure must increase. If the sample is fully saturated, an increase in cell pressure will result in an equivalent increase in pore pressure. Allow 10 to 15 minutes for the new pore pressure to stabilize and **again obtain and note transducer readouts of Pressure A and Pressure B.**

6. When the value of the pore pressure parameter B is $\geq$ 95%, the sample is considered to be fully saturated and you may proceed with the triaxial compression test. The calculation is carried out as follows using the pressure changes noted between the two readouts taken above:

$$B = (\text{change in back pressure}) / (\text{change in cell pressure})$$

$$= (\Delta \text{ Pressure B}) / (\Delta \text{ Pressure A})$$

If B < 95%, gas is present in the sample and you must increase the back pressure to

dissolve it. **Close valves B and C** and **open valves D, E, and Q. Increase back cell pressure** about 3 psi by increasing flow from Air Regulator #3. Then, **close valves D, E, N, and Q** and **open valves B and C. Increase the confining cell pressure** by about 3 psi from Air Regulator #2. (The new confining cell pressure should be 2 to 3 psi above the new back pressure). Wait at least 15 minutes, then repeat the steps in Paragraph 2 of this section to get the new pressure transducer readouts. Repeat the procedures in this paragraph, at back pressure increments of about 3 psi, until you obtain a value of B $\geq$ 95%. Record the B value on the Loading Sequence data sheet along with the back pressure value at which you obtained saturation. Leave the back pressure set at this value for the remainder of the test.

7. To equalize the confining and back pressures, **open valves B and C**, then **decrease the pressure supply from Regulator #2** until the wall gage reads a pressure equal to the back pressure. **Close valves B and C.**

Consolidating the Sample

1. The sample can now be consolidated. A recommended loading sequence is to start at a very low load and then double the previous load with each increment. Depending on the load applied, the components of the triaxial apparatus may be under considerable pressure. Be especially careful not to move or jar either the tubing or the lucite cells. This can easily result in broken tubing and connections. The sudden release of pressure will cause loose tubing to whip about wildly and will also spray water over nearby electrical components. Both of these situations are extremely dangerous.

2. To allow the pore pressure built up during the saturation test to dissipate, **open knob valves H and I** on the VCD (full inward position if the VCD piston is down; full outward position if the piston is up) and wait about 15 minutes. **Return valve I to the half-way (closed) position.** This is the valve you are using to open or close the system for drainage. It is very important that the triaxial cell be closed to drainage before you apply the load so double check the position of this valve. Now **close valve P.** Valve F remains closed and knob valve H remains in the full inward position.

3. Change directories on the computer to the data directory: **type CD\DATA**. The cursor prompt should now read C:DATA>. When it does, **type CLR** to clear old data files. (Never use the CLR command when you are not in the Data director. You will lose everything!) **Type TriaxA** (or TriaxB if you are on Unit B). The computer will ask you to

specify an LVDT. **Type 1333** (or 1273 if you are on Unit B). You will then be asked to specify a test time in seconds. **Type 500** but do not hit the return key yet.

4. To apply a consolidation stress (load) the confining pressure in the load cell must exceed the back pressure on the sample. The difference between the two is the effective load stress on the sample. Now, **hit the carriage return** to begin recording data. Immediately **open valves B, C, and P**. Now, **fairly quickly but not suddenly, raise the compression cell pressure** (Regulator #2) to a level such that the cell pressure minus the back pressure equals the desired load. The reason you open the compression cell to load pressure and start the test before you actually increase the load pressure is to avoid hitting the cell with an air hammer. If you were to apply the load first, and then opened valve P, it would be like striking the compression cell with a hammer blow. This could conceivably cause the lucite to shatter; with you standing next to it! Watch the pressure readouts. The confining pressure (pressure A) transducer readout should equal the value you applied on Regulator # 2. As the system is not yet open for drainage, the pore pressure (pressure B) transducer reading will increase to a value approximately equal to the confining pressure. You are performing a test analogous to a Slug, or Packer test by making a record of this pore pressure increase for latter evaluation.

5. When data recording stops, answer the prompt for another test: **type N**, then hit Return. Insert a formatted 5.25 in. floppy disk in the hard drive. (The hard drive itself is drive C; the floppy drive is drive A.) To read the floppy **type A:**. The screen cursor should change to A:\>. If you have inserted a previously used 5.25 in. disk, **Type DIR** to get a list of files already stored on the floppy. To make room for the new data, delete all of the old files on the floppy: **type DEL *.*** (make sure you are in drive A:). **Type C:** to return to C drive (the cursor should again read C:\DATA>). **Type COPY TriaxA.DAT A:** (or TriaxB.DAT, as appropriate) to copy the test data on to the floppy in drive A. Rename this new data file (so it won't be written over when you transferee more data latter): **type REN TriaxA.DAT T1L1U.DAT** or T1L2U.DAT, or T7L6U.DAT as appropriate, i.e., T = test number, L = load number (the U after L means the sample was undrained, that is, not allowed to consolidate). **Type C:** to return to drive C:\DATA>.

6. **Open valve E**. Place a copy of the "logt" data sheet (Appendix B) on a clipboard for recording VCD versus time data. You are now ready to consolidate the sample under the applied load. Make sure you are in the DATA directory and then again **type CLR** to clear old data. Then **type TriaxA** (or TriaxB as appropriate). Answer the prompts as

before specifying a test time of 900 seconds, then **hit the carriage return** to begin recording. **Immediately open valve I** (by pushing it to the full-in position if you are starting with the VCD piston in the down position; full-out if the piston is in the up position) and also start to manually **record VCD output at the times specified** on the logt data sheet. Opening valve I allows drainage, i.e., consolidation to begin. (You can use either valve I or H for this.) The excess pore pressure created by loading the sample without drainage will now begin to dissipate, i.e., pressure B readings will decrease, rapidly at first and then more slowly and will eventually stabilize at the value the back pressure is set at. You can plot this data to obtain a pore pressure decay curve from which permeability may be determined.

7. The water expelled from the sample will be forced (against the back pressure) through the volume change cell and into the back pressure cell. Since the sample volume is changing, the VCD readout will change; rapidly at first and then more slowly as the test proceeds. If VCD valves are still changing at the end of the 1800 seconds of test time, or if excess pore pressure is still present (pressure B has not yet dropped back down to the back pressure value), consolidation is not yet complete and you need to continue recording data. Consequently, you must **make a running plot of the change in VCD values versus log time** (a time-compression curve) during consolidation (for each load increment) to be sure that you are through primary, and into secondary, consolidation before terminating the load. Use a Time Compression Form (Appendix B) for constructing this graph. After the computer has recorded VCD output for the 1800 seconds specified (there is insufficient disk space for much more), continue to record VCD data manually until your time-compression plot indicates that the sample is in secondary consolidation. Do not be fooled into thinking you are in secondary consolidation when the VCD readout values are changing very slowly. If the sample is slow to consolidate, you will see very gradual changes in the transducer readouts. Fine grained samples will often require about 24 hours for each load however, since you are making a log of time graph, only a few data points will be required after the first half hour. Drainage (consolidation) can be stopped when the sample is in secondary consolidation.

8. If the sample is in secondary consolidation at the end of the test time, stop drainage: **close valve I** (move it to the half way point, i.e., between the all the way out and the all the way in positions). **Record the load, final readouts of Pres. A and Pres. B transducer (under Confining/Pore), final VCD value, and the room temperature** on the loading sequence data sheet. Then answer no to the prompt for another

test: **type** N. Insert the 5.25 in floppy disk in A drive. Then **type COPY TriaxA.DAT A:** (or TriaxB.DAT, as appropriate) to copy the load data on to the floppy. Again, **rename** this new data file (so it wont be written over latter): **type A:** and then **type REN TriaxA.DAT T1L1D.DAT** using the appropriate test and load numbers. Notice that a "D" is now used after the load number (indicating that the sample was allowed to drain). **Type DIR** to make sure the files were copied to the floppy in drive A:. **Type C:** to return to drive C:\DATA> and then **type Copy TriaxA.RAW A:** to copy the raw data (transducer output in millivolts) to the floppy in drive A. Open the A drive directory: **type A:** and then **type DIR**. You should see three files listed as stored on the floppy in drive A:T1L1U.DAT, T1L1D.DAT, and T1L1D.RAW. (It is not necessary to save the T1L1U raw data.) **Record these file names** on the loading sequence data sheet. Now **type C:** to return to C:\DATA>.

9. Raise the triaxial compression cell, via the electric motor, until the top of the sample cap is again in contact with the load cell piston. It will have dropped down a slight distance because the sample has undergone consolidation: **flip the ON/OFF switch to On** at the Triaxial Unit control panel, then **push the Up button** marked "adjust platen". Be very careful not to squeeze the sample against the ram by holding the Up button in to long. Next, **run a brief test** on the data acquisition system (i.e., type TriaxA, etc.), five seconds is sufficient, to get a new LVDT readout. You do not need to save the data from this brief test on to a floppy but make sure that you **record the new LVDT value** on the data sheet. The change in LVDT readings between loads represents the change in height the sample has undergone during consolidation. This data is used to calculate velocities. As a backup, also **measure the distance from the base of the triaxial cell to the Triaxial Units base** after each load and **record it under "Final Platen"** on the Loading Sequence data sheet.

10. Determine the post-consolidation sample velocity values by repeating the procedures for both compressional and shear waves specified in the Section on **Velocity Data Acquisition** after each load increment during the test. Be sure to **record the new velocities and the signal file names** on the wave form data sheet.

11. Repeat the procedures specified in this section using successively higher loads according to your predetermined loading sequence. The highest pressure that our Triaxial Units are designed for is 145 psi (1000 kPa), marked in red on the wall gages. These units are old and the Lucite does deteriorated with age. Consequently, you should allow for a

safety factor, i.e., **do not exceed 120 psi**. The total volume change equals the sum of the volume changes that occurred during saturation and consolidation.

Shearing the Sample

1. Samples can be sheared in our system. However, our set-up is not recommended for conventional strength testing because the cells pedestals and caps have been modified to accommodate velocity transducers. As a result, the space available within the compression cells will no longer accommodate samples that have the length to width ratio recommended for accurate determination of shear strengths. A larger compression cell must be used when standard shear strength tests are planned. If you plan to determine the shear strength of the sample, you should consult one of the standard reference texts for a detailed description of laboratory procedures and calculations.

Termination of the Test

1. Turn on the triaxial machine's electrical control panel and use the platen switches to lower the compression cell most the way down.

2. Slowly, turn off the air regulators: **turn off Regulator #3** (back pressure) well ahead of the load cell regulator to avoid excess effective back pressure that will expand the sample. Slowly, **turn off Regulator #2, then Regulator #1** (cell pressure and main supply, respectively). Then **turn off the main air supply valve.**

3. **Turn off the transducer switches** on the data acquisition box (red lights should go out) and **disconnect the transducers cables** from the box.

4. After the bladders in the confining pressure and back pressure cells have expanded to normal size and you are sure they are no longer under pressure (slightly open their air vents if you are in doubt), **open the air vent on the triaxial compression cell.** Then, **close all other valves** on the whole system. **Open valve P and the drain valve** and allow the water in the triaxial compression cell to drain into a large bucket.

5. After the compression cell has drained, raise the load frame and unscrew the cell's metal cap. Lift the compression cell assembly (the metal cap, load cell piston, and Lucite cell) off the machines base and set it aside.

6. Remove the sample and **collect a post-consolidation fabric sample.**

(Follow the procedure used for taking a pre-consolidation fabric sample.) Make a check mark in the appropriate space on the Physical Properties data sheet to indicate that you have collected this sample.

7. Place the remainder of the consolidated sample in a labeled beaker for drying and weighing. You will need the final, dry sample weight to **calculate the Height of the Solids.** (You will have to calculate the dry weight of the fabric sample and add it in when calculating height of the solids.) Record these data on the Physical Properties data sheet. Place the remaining dryed sample in a plastic bag and store it, along with the post-consolidated fabric sample, in the storage refrigerator.

8. Flush water through the drainage hole in the pedestal base until the water is clear. This is important because if clay particles from the sample settle inside the drain, it will become clogged and difficult to clean latter when the clay has dried.

9. If you are not going to begin another test soon, drain the other cells and empty the deaerator reservoir: run the tygon drain line to the sink and **open the pinch clamp.** Then **open the Vent Valve** (full counter clockwise position) and allow the system to drain completely.

DATA PROCESSING

1. You now have several 5.2-in floppy disks containing data in a series of files for each load increment during the test, i.e., T1L1U.DAT, T1L1D.DAT, T1L1D.RAW for load number one of test number one, etc. Using the Bernoulli BOX II (IBM compatible) and the special System Diskettes, copy the data files on the 5.2-in floppies into ASCII Format on 3.5 inch diskettes for back-up and for compatibility with other computers: **Insert the special diskettes marked System C and System D into C and D drives,** respectively, on the Bernoulli hard drive and then boot up the computer.

2. **Copy all the data files** on the 5.2-in floppies to D drive. **Insert a formatted 3.5-in diskette into drive B** and copy all of the data files from D drive to the 3.5 inch diskette in drive B. They will be copied in ASCII Format. **Label the 3.5-in diskette,** indicating the test number, triaxial unit on which the test was conducted (A or B), and the data file names.

3. **File all the data forms and diskettes** for the test. Test files should contain: 1. Physical Properties data sheet, 2. Loading Sequence data sheet, 3. Wave-Forms data

sheet, 4. a 3.5-in. diskette with Wave Form files (from the Oscilloscope), 5. several 3.5-in. diskettes with all of the triaxial compression data, 6. time compression data not saved on diskette, and 7. a time compression plot for each load increment of the test.

ACKNOWLEDGMENTS

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APPENDIX A. DATA FORMS

PHYSICAL PROPERTIES: TRIAXIAL COMPRESSION TEST SAMPLE DATA

TEST No. ____________________

Sample No. __________________

Date ________________________

Sample Description ____

____

Volume:

Diameter (cm) Top _______ Center _______ Bottom_______

Length (cm) _____________

Water Content:

No. 1 Tare (g) _________

Tare + wet soil (g) _________

Wet sample Wt. (g) ________

Tare + dry soil (g) _________

Dry sample Wt. (g) ________

Water Content No. 1 (%) ________

No. 2 Tare (g) _________

Tare + wet soil (g) ________

Wet sample Wt. (g) _______

Tare + dry soil (g) ________

Dry sample Wt. (g) _______

Water content No. 2 (%) _________

<u>**Unconsolidated Sample**</u>

Tare (g) _________

Tare + wet sample (g) _________

Wet sample Wt. (g) ___________

<u>**Consolidated Sample**</u>

Tare (g) _________

Tare + dry sample (g)__________

Dry sample Wt. (g)___________

Strength: Vane Shear or Pocket Penetrometer __________kg/cm^2

Trimmings Collected for:

1. Grain Size _____
2. Pycnometer _____
3. Atterberg Limits _____
4. Pre-Consolidation Farbric _____
5. Post-Consolidation Fabric _____
6. Remaining Whole Round saved (cm) _________

LOADING SEQUENCE: TRIAXIAL COMPRESSION TEST SAMPLE DATA

TEST No. ________________

Sample No. ________________

Date ____________________

Zero Readings:

Cell Press. XRD (psi)	Pore/Back Press. XRD (psi)	LVDT (in)	Platen (cm)	VCD (cm^3)

Saturation Back Pressure: _________(psi) **Saturation B value:**__________

Loading Sequence:

Eff. Stess (psi)	Confining/Pore (XRD-psi)	Final LVDT (in)	Final Platen (cm)	VCD (cm^3)	Temp (C^0)	Data File Name

Remarks:____

____

____

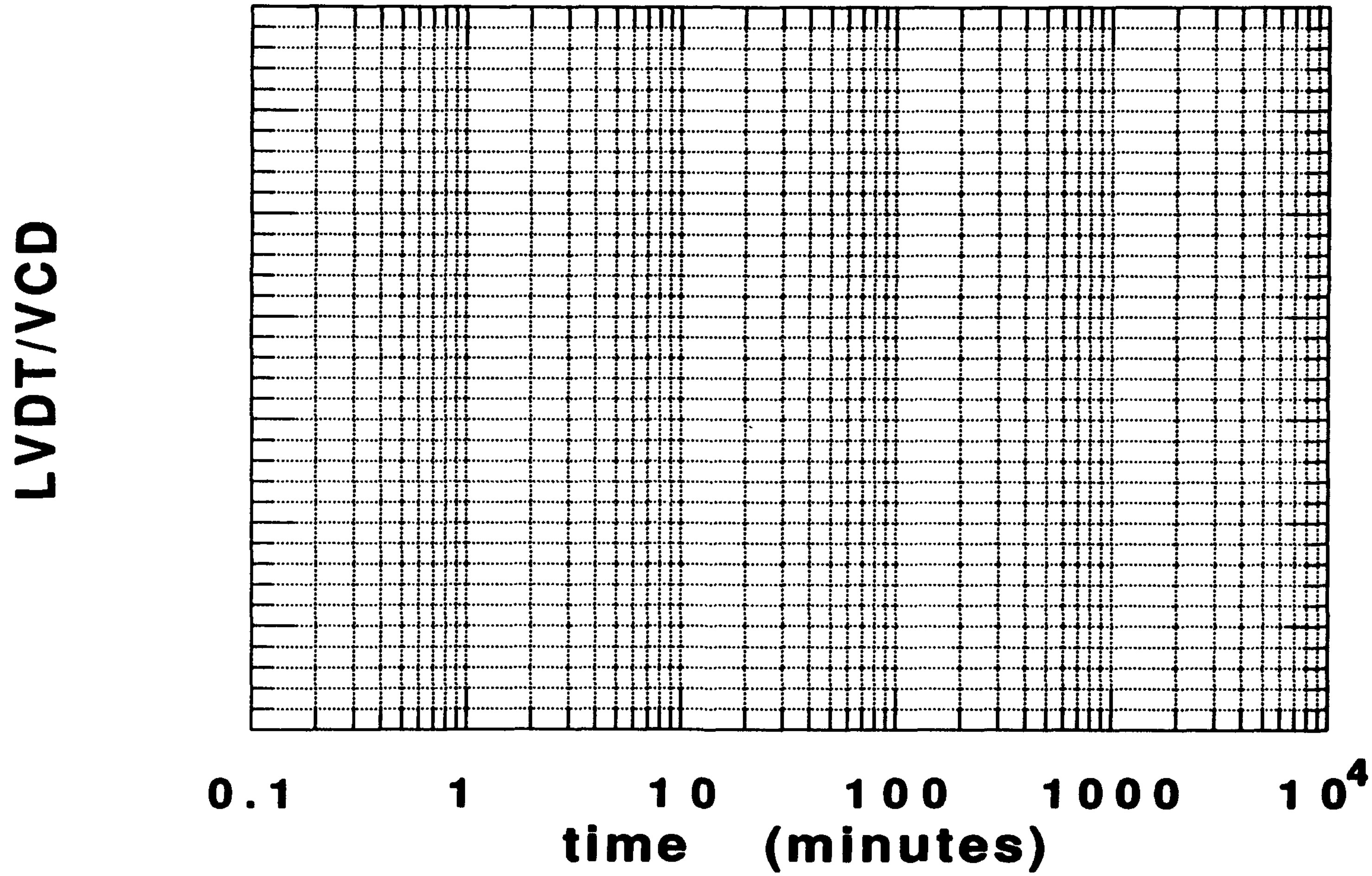
____

____

Tests Performed by: ______________________

Test______	Load______			Test______	Load______		
Date	Time	Elapsed	VCD	Date	Time	Elapsed	VCD
		Time (min.)	Reading			Time (min.)	Reading
		0				0	
		0.25				0.25	
		0.5				0.5	
		0.75				0.75	
		1				1	
		2				2	
		4				4	
		8				8	
		15				15	
		30				30	
		60				60	

Time Compression: Test ______, Load ______



WAVE-FORMS: TRIAXIAL COMPRESSION TEST SAMPLES

Test No______Sample No. __________________Date _____________Page ___of ____

Zero Load:	Freq. (kHz)	Ampl.(Volts)	Time Delay (u-sec)	Velocities (m/s)
P-wave:	________	________	________	________
S-wave:	________	________	________	________

Original Sample Ht.: = ________cm (P-vel), - 2 x 0.73 (Probes) = ________cm (S-vel)

Effective Load (psi) _____, Settings: Freq. _____, Ampl. _____, Power Amp. X ____

P-wave:	New Ht. (cm)	Time Delay (u-sec)	Wave Form Files
	_______	______	__________

P-wave Velocity = (new Ht.) / (time delay) = __________(m/s)

Effective Load (psi) _____, Settings: Freq. _____, Ampl. _____, Power Amp. X ____

S-wave:	New Ht. (cm)	Time Delay (u-sec)	Wave Form Files
	_______	______	__________

S-wave Velocity = (new Ht.) / (time delay) = __________(m/s)

Effective Load (psi) _____, Settings: Freq. _____, Ampl. _____, Power Amp. X ____

P-wave:	New Ht. (cm)	Time Delay (u-sec)	Wave Form Files
	_______	______	__________

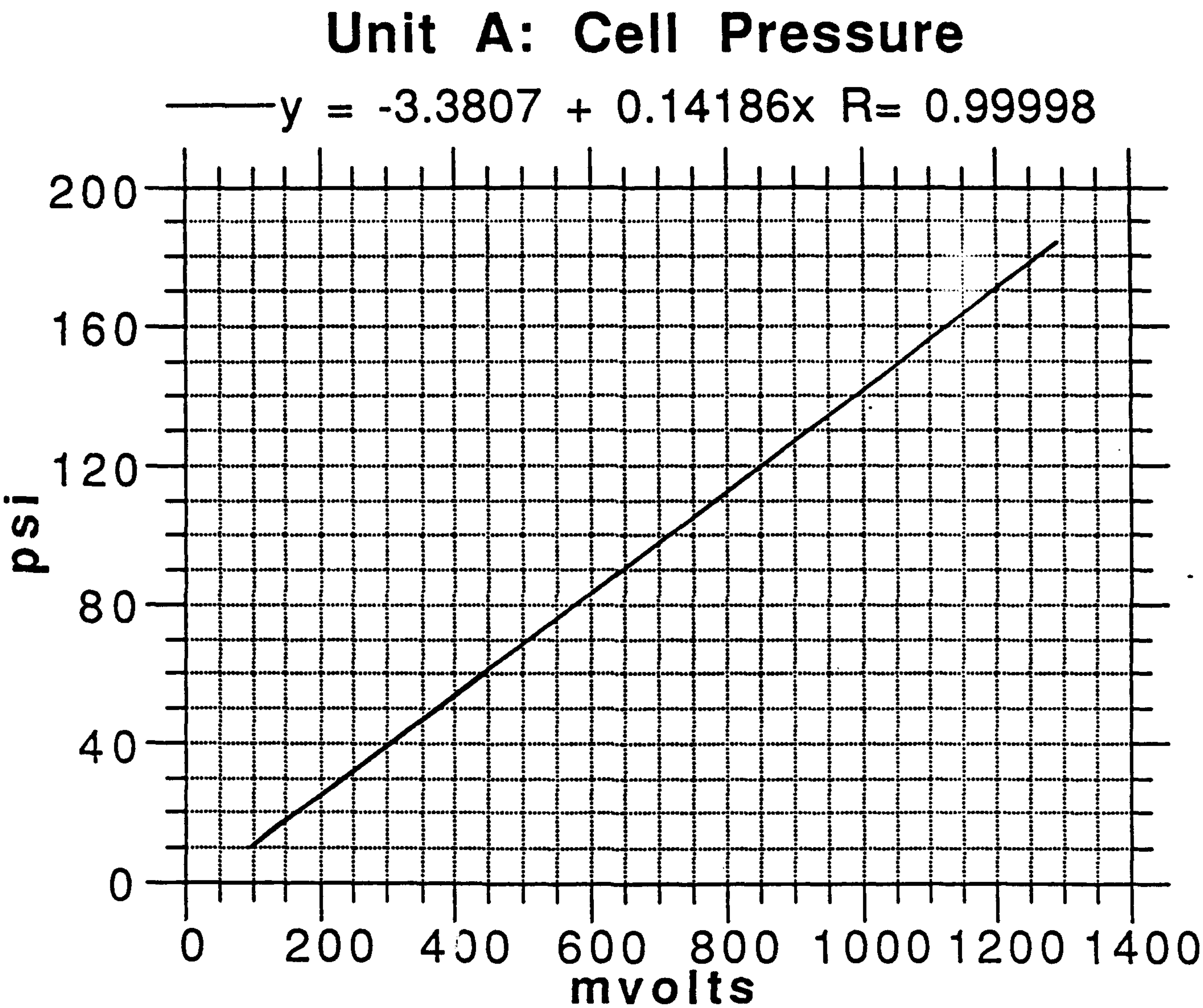
P-wave Velocity = (new Ht.) / (time delay) = __________(m/s)

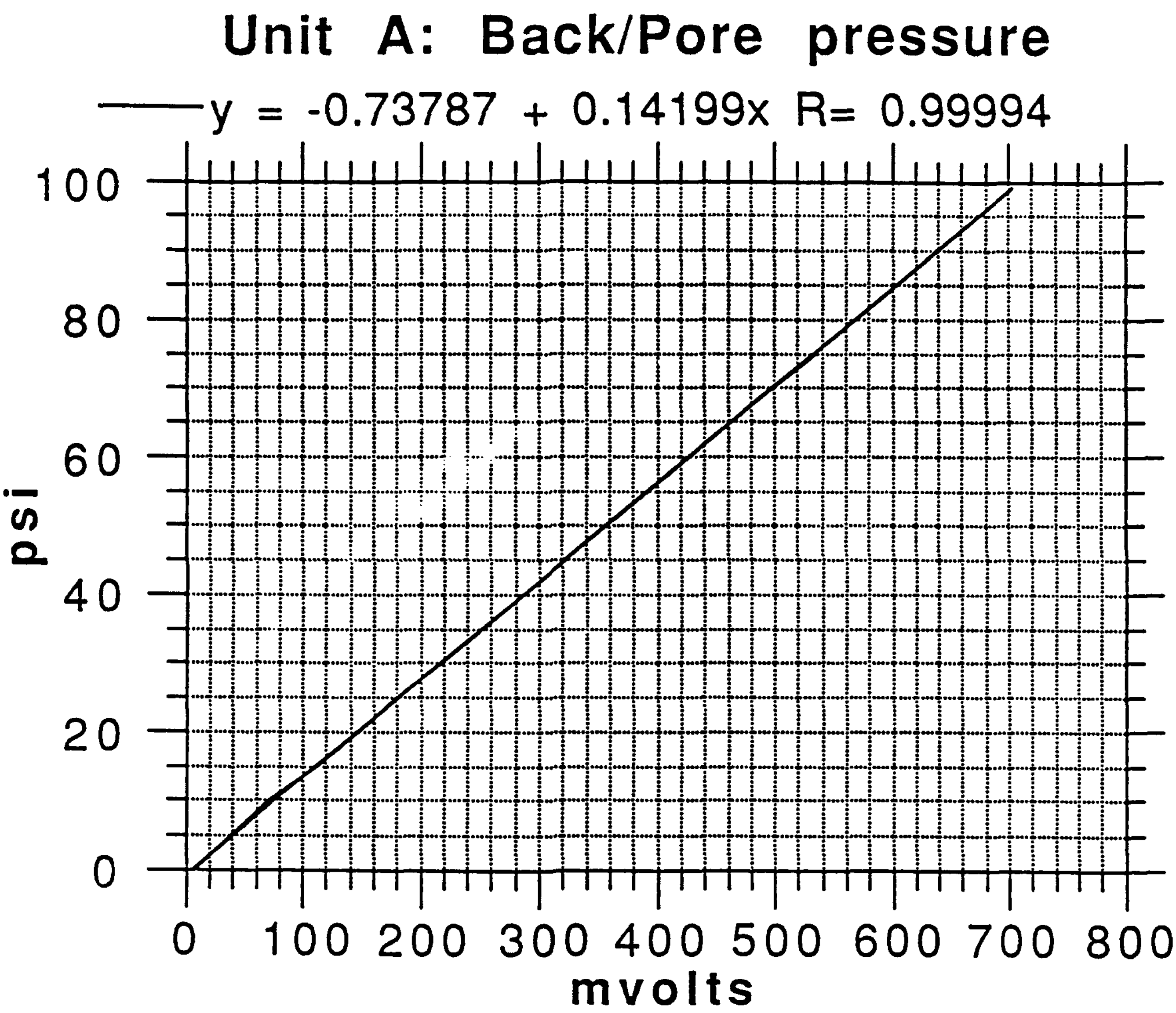
Effective Load (psi) _____, Settings: Freq. _____, Ampl. _____, Power Amp. X ____

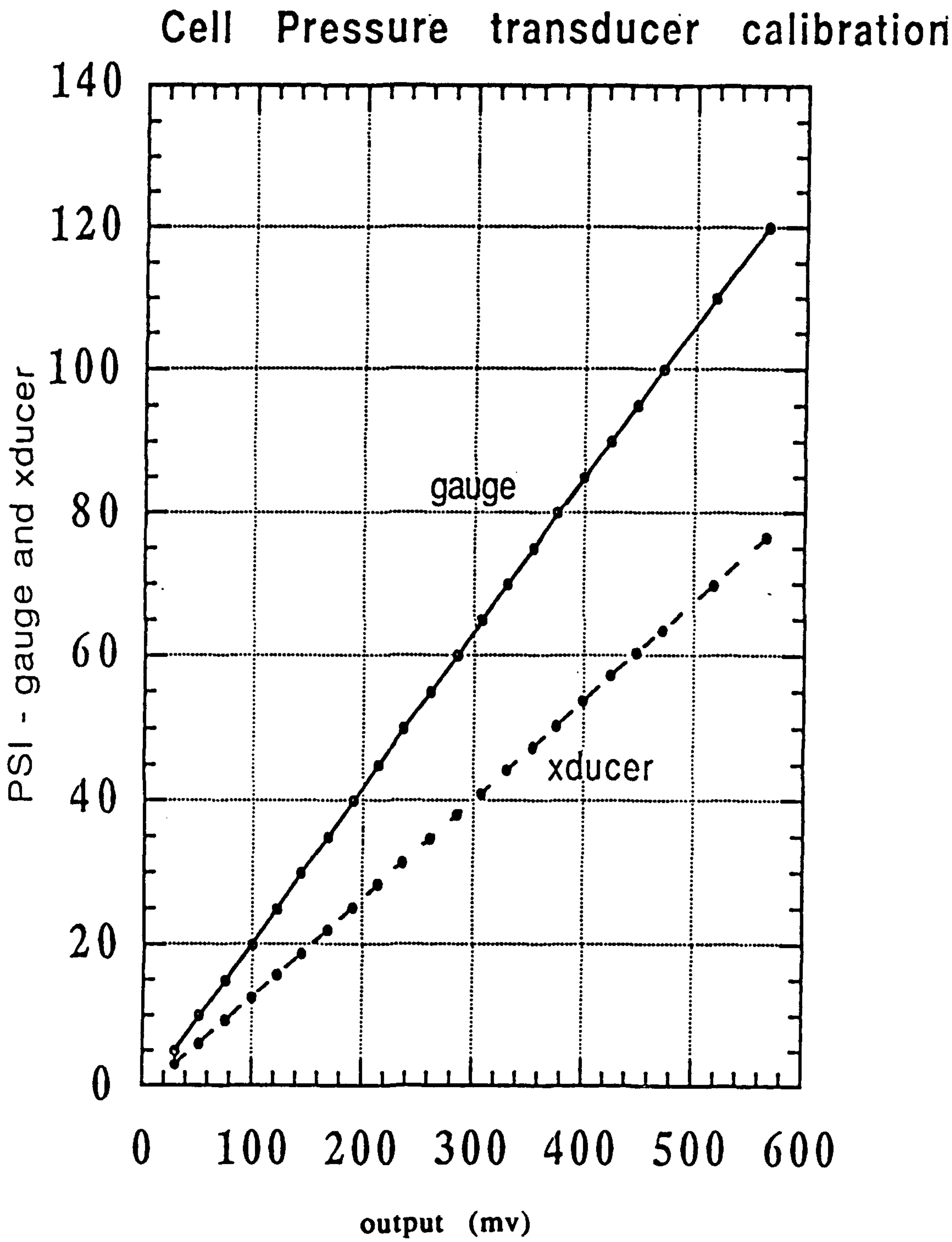
S-wave:	New Ht. (cm)	Time Delay (u-sec)	Wave Form Files
	_______	______	__________

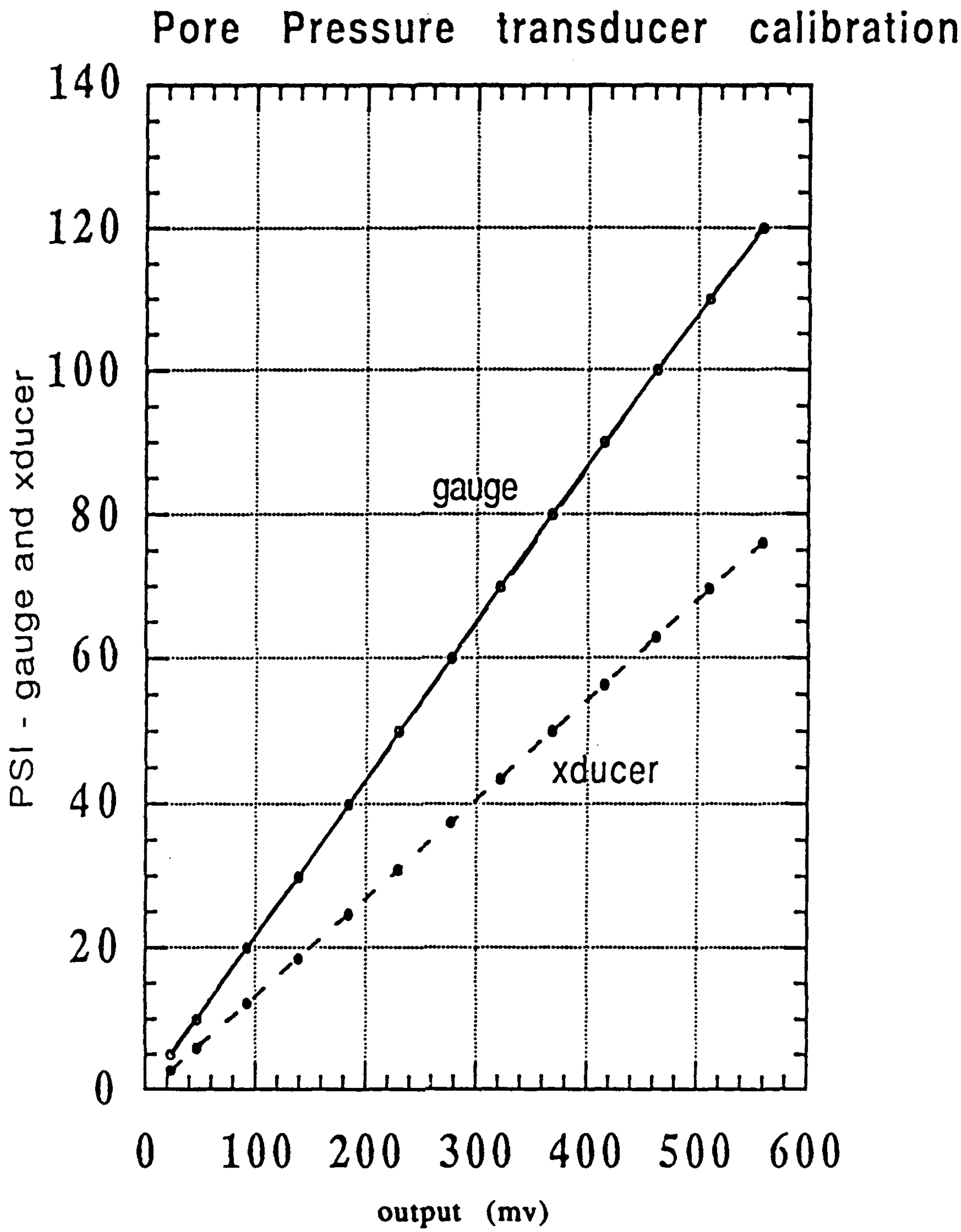
S-wave Velocity = (new Ht.) / (time delay) = _________(m/s)

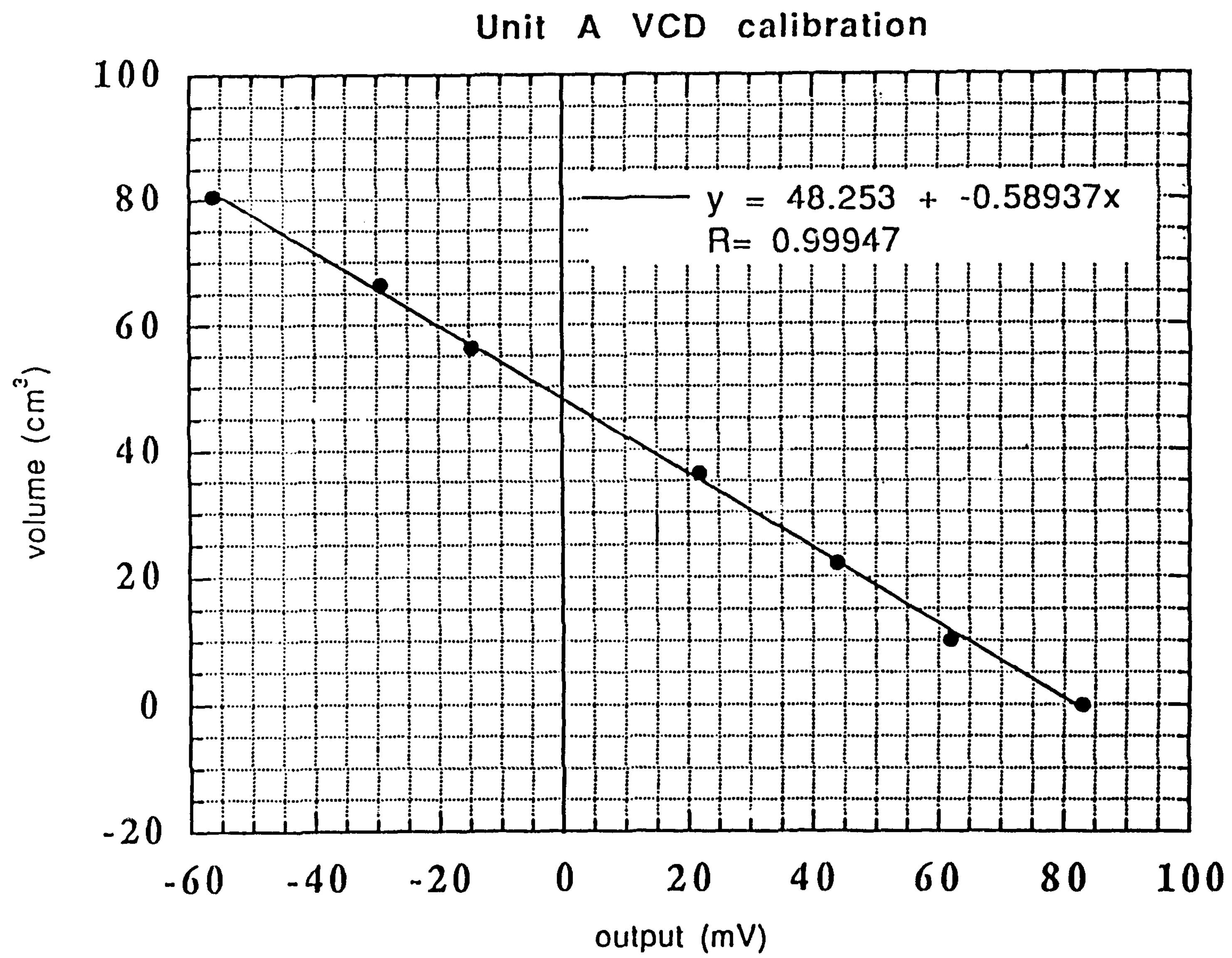
APPENDIX B. TRANSDUCER CALIBRATION CURVES

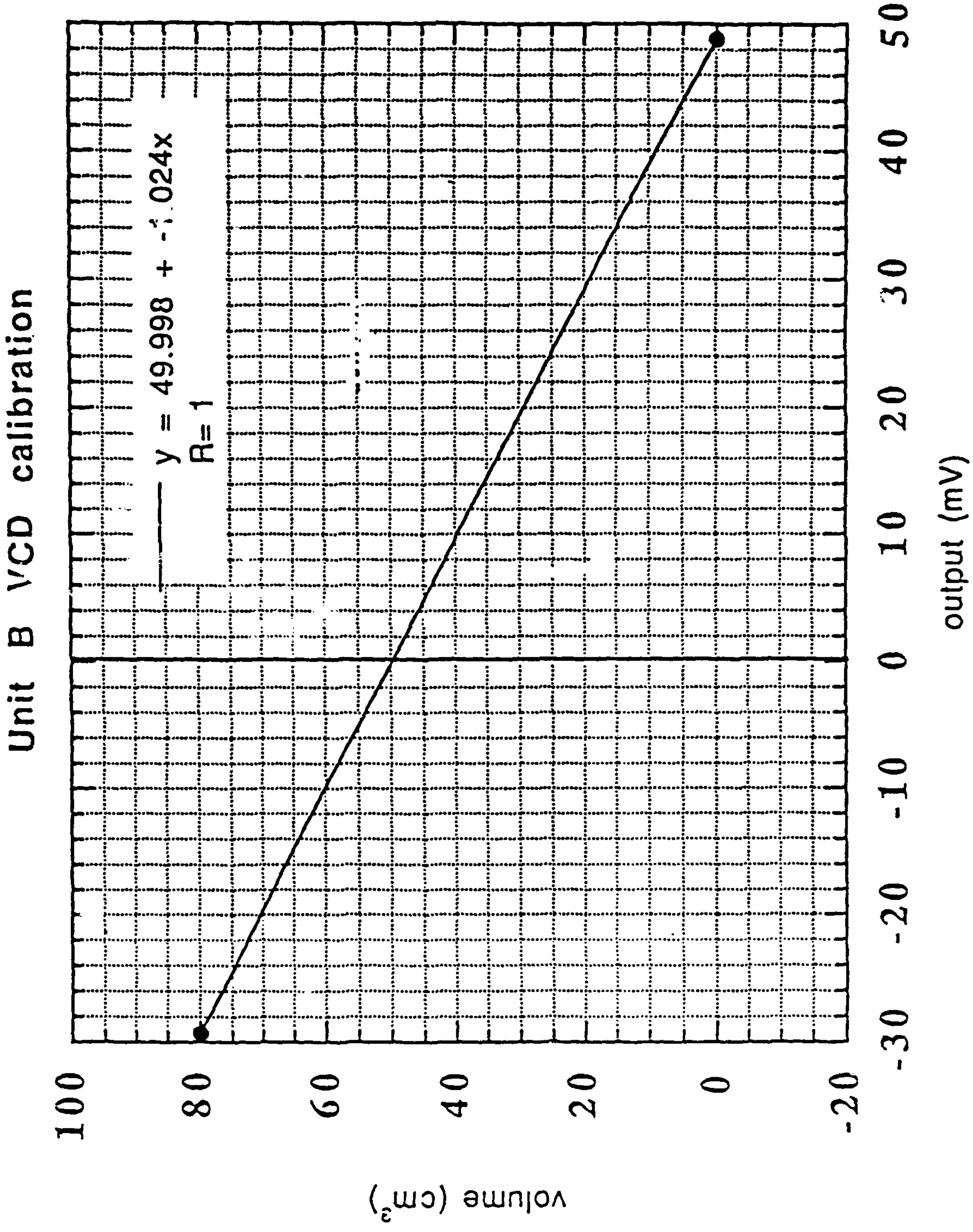

Unit A: Cell Pressure
y = -3.3807 + 0.14186x R= 0.99998
200
160
120
80
40
0
psi
0
200
400
600
800
1000
1200
1400
mvolts

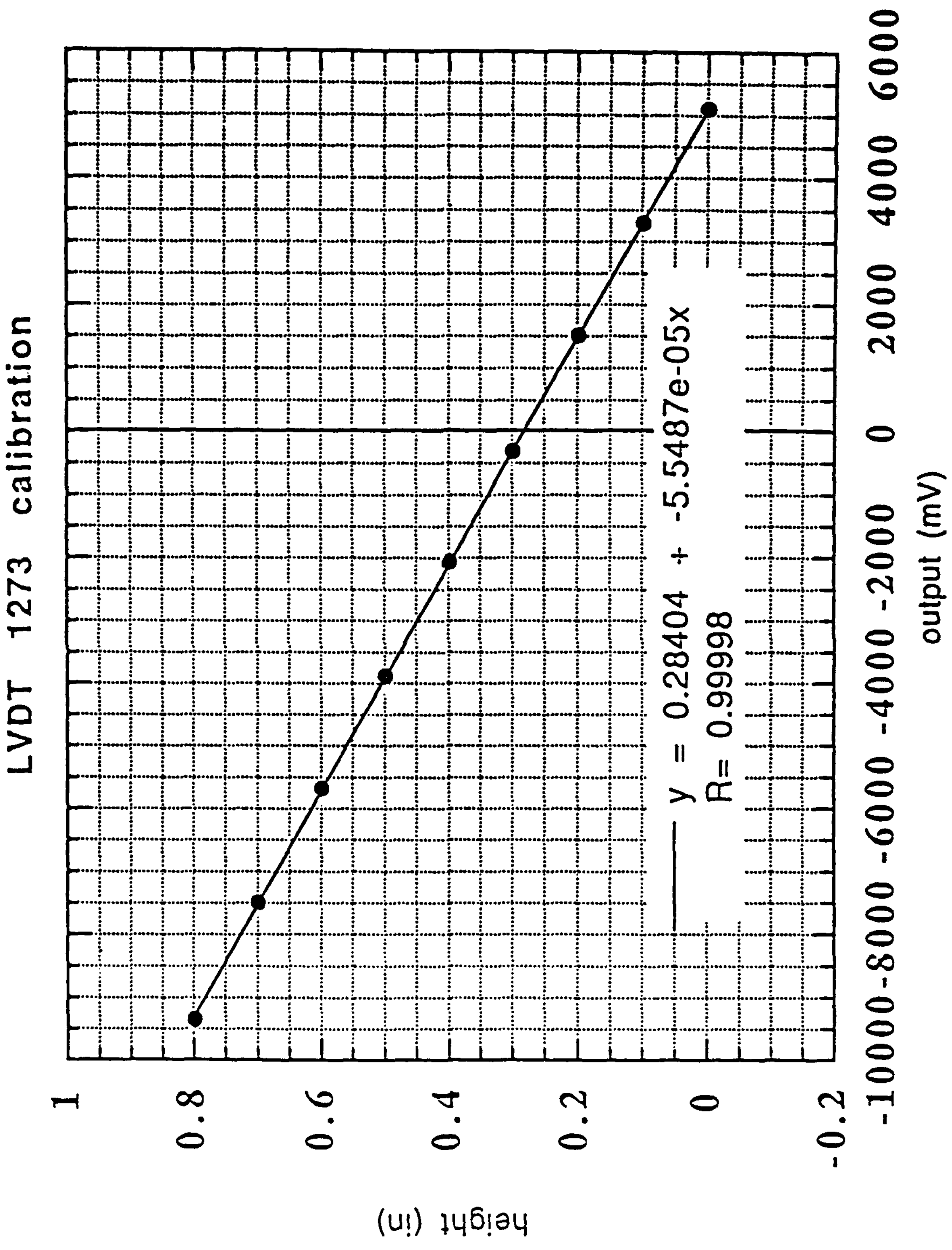

Unit A: Back/Pore pressure
y = -0.73787 + 0.14199x R= 0.99994
psi
0
20
40
60
80
100
0
100
200
300
400
500
600
700
800
mvolts

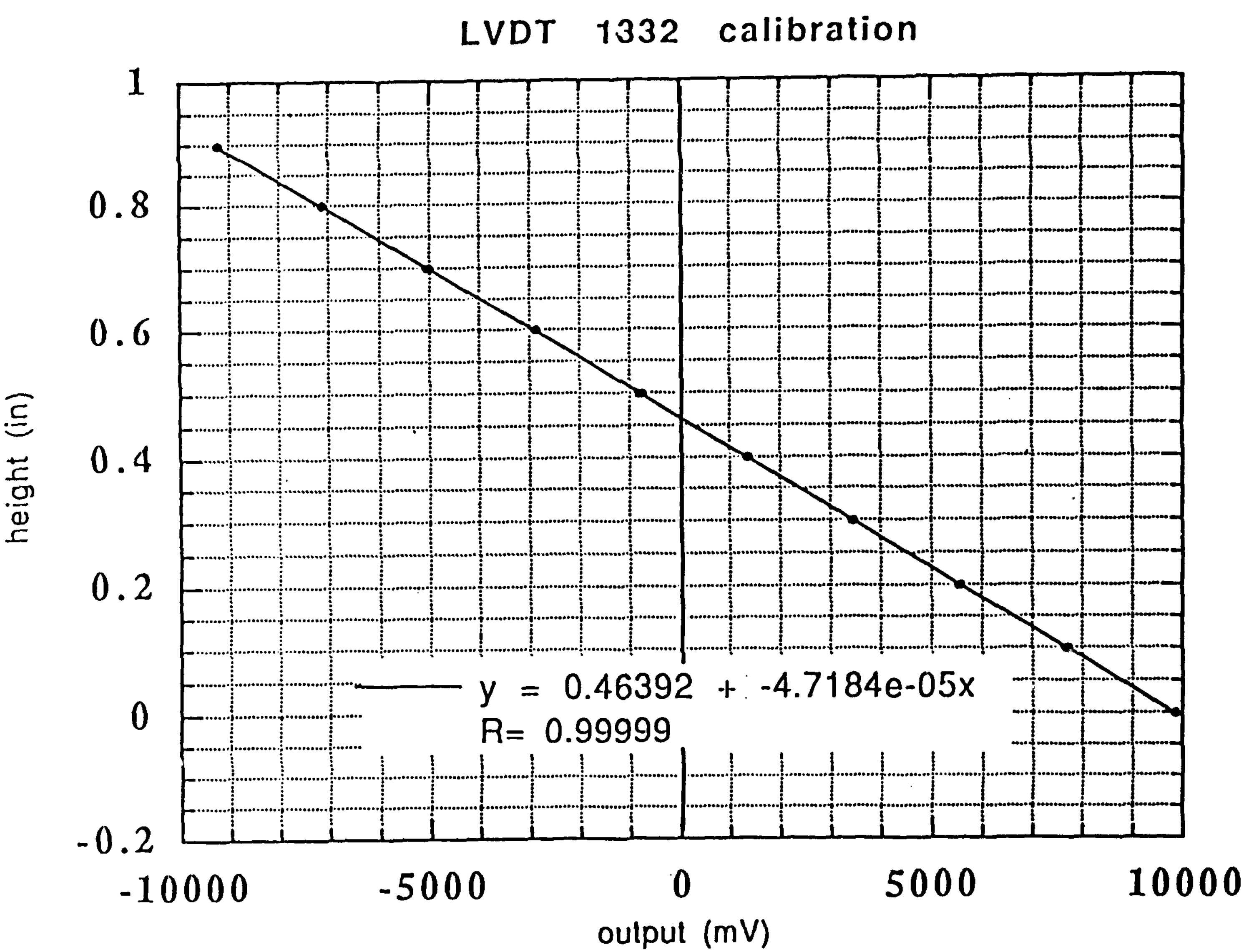

Cell Pressure transducer calibration
140
120
100
80
60
40
20
0
PSI - gauge and xducer
gauge
xducer
0
100
200
300
400
500
600
output (mv)


Pore Pressure transducer calibration
PSI - gauge and xducer
140
120
100
80
60
40
20
0
gauge
xducer
0
100
200
300
400
500
600
output (mv)


Unit A VCD calibration
y = 48.253 + -0.58937x
R= 0.99947
volume (cm³)
output (mV)
100
80
60
40
20
0
-20
-60
-40
-20
0
20
40
60
80
100


Unit B VCD calibration
y = 49.998 + -1.024x
R= 1
output (mV)
-30
-20
-10
0
10
20
30
40
50
volume (cm³)
-20
0
20
40
60
80
100


LVDT 1273 calibration
y = 0.28404 + -5.5487e-05x
R= 0.99998
height (in)
output (mV)
1
0.8
0.6
0.4
0.2
0
-0.2
-10000
-8000
-6000
-4000
-2000
0
2000
4000
6000


LVDT 1332 calibration
height (in)
1
0.8
0.6
0.4
0.2
0
-0.2
-10000
-5000
0
5000
10000
output (mV)
y = 0.46392 + -4.7184e-05x
R= 0.99999